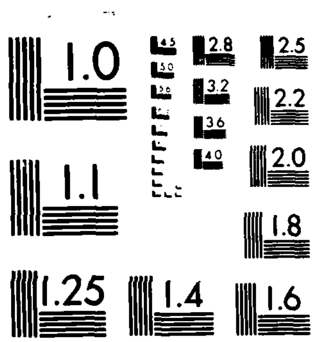

MICROCOPY RESOLUTION TEST CHART
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A. Front Cover

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FINAL SCIENTIFIC REPORT

FOR

ANGULAR-RESOLVED ELECTRON EMISSION STUDIES OF MICROWAVE MATERIALS

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Photoemission spectroscopy; Electronic structure; Band structure; Surface states; Angle-resolved electron emission, Synchrotron radiation, III-V semiconductors; Gallium Arsenide; Indium Phosphide; Indium Antimonide; Indium Arsenide, Gallium Selenide, Tungsten; Nickel; Polarization effects; Wave function symmetry, Chemisorption; Oxidation; Fermi level pinning; Band bending; heterojunctions.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Experiments were performed to determine the electronic structure of III-V compound semiconductors and transition metals, for example, the cleavage surface of gallium arsenide and tungsten. The results, in addition to contributing to an understanding of these materials, formed the necessary background information for interpreting the fundamental physical and chemical properties of adatoms on the surfaces. Several overlayer systems were studied with emphasis being placed on Ge and GaAs(110) and oxygen on W and hydrogen on W. Theoretical modeling

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indicates that Ge monolayers essentially exhibit the interface states expected for the Ge/GaAs(110) heterojunction. Ultraviolet photoemission (UPS) was the method used to measure the electronic structure which included the new techniques of angular resolution and polarization dependence. Synchrotron radiation was used as the radiation source so advantages of the polarizer, continuum extending into the far ultraviolet could be employed. Several of these experimental methods used to measure and interpret UPS data were developed in the program, for example, polarization-symmetry analysis and photon energy scanning of core threshold behavior. Core threshold studies yield information on the conduction band density of states (bulk and surface) and decay processes of the core hole. Studies were performed for the shallow levels of GaAs(110), GaSe, and Pt.

B. DESCRIPTION OF GRANT EFFORT AND RESULTS

a. Introduction

The purpose of the program was to investigate the electronic structure of solids, surfaces of solids, and adsorbed molecules by employing the methods of polarization-dependent angle-resolved ultraviolet photoemission (PARUPS). As a source of radiation we used synchrotron radiation available from the storage ring at the University of Wisconsin Synchrotron Radiation Center. At the inception of the program PARUPS was a relatively new field, so contributions were also made to the development of the methods and their applicability to the study of solids and their surfaces. As necessary, other methods of surface analysis were integrated into the program.

The materials studied were selected for their scientific importance as well as technological relevance. A number of studies were performed on transition metal surfaces which, in addition to their own scientific and technological interest, served as good model systems for developing the methods of PARUPS utilizing synchrotron radiation. The III-V compound semiconductors formed a major emphasis for the research studies since they are extensively used in the semiconductor device industry. The compound semiconductor surfaces are much more complex systems than elemental metals, requiring a much larger laboratory effort to obtain specific results. Considerable sophistication is required in preparing well characterized meaningful samples. A fundamental understanding of molecules at

surfaces is important because a large number of technological components and processes involve the properties of surfaces or interfaces, for instance electronic junction devices such as Schottky barrier diodes and heterojunctions, insulating and conduction layers on integrated circuits, thin films, and protective coatings for optical or mechanical purposes. The basic physics of surfaces and absorbed layers on them is needed to provide the conceptual foundations on which to build technological progress. The results of this program contributed to the development of these foundations which are still in a rather primitive state, particularly for compound semiconductors.

The results of the investigations performed in this program are found in the articles published in the journals of the open literature (see Section C for a listing). Also, a large number of conference presentations were made. As a result the narrative here is an overview summary of the research as performed.

Contributions made in this program can be considered from two prospectives. One is the development of spectroscopic methods for studying surfaces, and the other is the development of an atomic understanding of the surfaces. These developments made it possible in the last months of the program to find some interesting properties of surfaces.

b. **The Research Methods and Developments**

The integration of angle-resolved photoemission with synchrotron radiation as a source makes a very powerful tool for incisive measurements of the electronic structure of a sample

and such data can be used to infer fundamental properties of the sample. Angular resolution in ultraviolet photoemission means that, in addition to determining the initial and final energies of an electronic transition, one also directly measures the parallel component of the emitted electron's momentum (the component of the wave vector parallel to the crystalline surface). Determination of the perpendicular component for bulk bands is not measured directly and requires an interplay between theory and experiment. An example of the latter is the III-V conduction bands below 20 eV. This problem, which is very complex, was solved in this program (Publication 28, Section C). Figure 1 provides a summary of this result. Further, the polarization properties of synchrotron radiation make it possible in given geometries to directly measure the symmetry of the initial states probed by photoemission. A summary of these ideas is given in Publication 9, Section C, which was also given as an invited paper in the Second European Conference on Surface Science (ECOSS II).

A number of results were obtained which utilized the tunability of synchrotron radiation where either a photon energy range is scanned or any energy selected. In addition to performing studies which excite valence electrons as noted above, it is very useful to perform studies that use core level excitation, especially at threshold for core excitation. Procedures were developed and applied to several problems for infering from core threshold excitation measurements properties of conduction band states (surface and bulk) just above the band

gap. The threshold photoemission features also contain information on core hole decay processes, for example Auger or excitonic processes. A compilation of these methods is reported in Publication 2, Section C, and the methods were applied in a number of publications itemized in Section C.

Photoemission is the most direct method of measuring electronic structure, but it contains features due both to bulk-band surface-derived states. Hence, the first studies were directed to determining properties of clean crystals, thus an understanding of both bulk and intrinsic surface states was obtained. With such background information at hand one can then study the fundamental behavior of molecules on surfaces.

In this program major efforts were devoted to the cleavage surface of GaAs(110) and the tungsten surfaces (111) and (100). For adatom molecule studies a central focus was given to oxygen and and CO, and, in the case of GaAs(110), Ge overlayer studies were persued.

c. **Semiconductor Studies**

At this time the clean GaAs(110) cleavage surface is considered to be reasonably well understood because the atomic geometry and electronic structure model are in good agreement with experiments. In forming the cleaved surface tetrahedral bonds are broken leaving dangling bonds on the surface. Such bonds are very unstable and the surface relaxes so the dangling bonds are modified; the arsenic atoms move up and the gallium atoms move down with a charge transfer from Ga to the As. Our

studies of the angular and polarization dependence of the dangling bond surface states served as an important test for the relaxation models (see Publication No. 4, Section C). To study the conduction bands from threshold up to about 25 eV detailed normal photoemission spectra from GaAs and related III-V's were measured. By integrating the data with theoretical studies we are able to understand the spectra in detail by assigning each feature to a specific interband transition. The bands are calculated by K. Pandy. Such results are reported in Publication No. 28, and Fig. 1 shows the excellent correlation between observation and calculation. The GaAs(110) surface is one of the few semiconductor surfaces which is well understood even though a large effort has been made by the scientific community to determine properties of clean surface.

Core threshold studies for the As 3d core were performed on GaAs(110). These have been described in Publication No. 23 where we were able to infer properties of conduction band surface states. Also, by integrating these results with our earlier results obtained for the Ga 3d core threshold measurements, we were able to infer a binding energy for the Ga 3d core hole surface-state exciton, an important number in understanding theoretical models for excitons. Previously no measurement for the binding energy existed. In the case of the As core excitation we could find no evidence for an excitonic effect. [Similar core threshold studies were done for GaSe, a layered material, and the transition metals Ni and Pt.]

The problem of a fundamental understanding of an adatom's

behavior on a compound semiconductor surface is still largely unsolved. A detailed understanding of the clean surface needed for background information was done. The studies in this program were focused on Ge overlayers with the objective of finding the Ge-induced states on the GaAs surface. This system is considered a model system and theoretical studies show that the interface states predicted for heterojunctions are essentially present for low coverages of the order of a monolayer. In the experiment it turned out that such states are very weak. The results are reported in Publication No. 26 and the results indicate that more theoretical modeling is needed.

The Ge overlayer experiments led to the discovery that the most significant effects induced by the Ge are the shifts of the transitions resulting from the bulk bands. The shifts indicate that various portions of the bands shift by different amounts. What made this observation possible was the detailed understanding of the photoemission spectra from the clean surface. These observations were made near the end of the program and their consequences will be worked out later. The first potential consequence is that the usual picture of Fermi level pinning and band bending has to be modified since it is usually assumed that all the bands shift uniformly. Hence the use of UPS as a tool for overlayer-induced band bending studies has to be done with some caution.

At this time it is not possible to conclude that fundamental understanding exists for any absorbate on a compound semiconductor surface. This situation probably also applies to

elemental semiconductor surfaces; that is, a combined fundamental understanding of the electronic structure and the atomic structure of the surface. We believe that the methodologies and app.oaches reported by this program will make relevant contributions to the development of appropriate models.

d. **Transition Metals**

For investigating properties of transition metal surfaces tungsten was usually selected although several studies on Ni, Pt, and Nb were performed. Several practical reasons contributed to tungsten's selection, those being ease of preparing atomically clean surface (after initial cleaning, for example, about a second is required to get a clean surface) and a large literature of ancillary surface measurements. Additional motives for some of the experiments with transition metals were ease of sample preparation to facilitate testing investigation methods and procedures.

Both the tungsten (100) and (111) surfaces were studied. The (100) surface has a four-fold rotational symmetry, and the (111) surface has a three-fold rotational symmetry, a symmetry for which very few surface studies had been performed. The clean surfaces were studied to determine the contributions in the photoemission spectra by the bulk bands and by the surface bands. Much of the work for the clean (100) surface was performed before this program started. The study of the (111) surface was pursued in some detail after the initial discovery of a surface state excited by s-polarized light. The metallic literature at that

time contained the notion that the symmetry of metallic surface states is limited to that which can only be excited by p-polarized light. Quite good agreement between the W surface state measurements and theoretical surface band calculations exists which indicates that a good understanding of the origin of such surface states exists. Several papers were published on these various points. The principal publications would be No. 27 in Section C which also consider hydrogen adsorption.

Several studies with oxygen were performed on tungsten. Oxygen on the tungsten shows quite a complex behavior, particularly for the (100) surface. In examining the photon energy dependence of the oxygen-induced states on both the (111) and (100) surface we found strong emission amplitudes at 21 eV and about 31 eV. Upon examining the characteristics of these resonances, it was found that they were not consistent with the usual properties of photon energy dependences, that is density of states (photoelectron diffraction) or shape resonance effects. These effects are reported in Publication No. 18. There are a number of observations which lead to this conclusion, but perhaps the most incisive one is the observation that if one measures only normal emission while changing the angle of incidence of the radiation, the value of the photon energy for the resonance near 31 eV depends on this angle of incidence. As a result a model was developed that attributed these resonances to be the result of a surface photoeffect in the following sense. When radiation is incident on a substance, the dielectric response of the media causes the radiation field inside the surface to be different

than the incident radiation field. It is possible that this field can have strong enough gradients to provide for momentum conservation in the photoemission process, thus eliminating the requirement for the umklopp process which usually conserves momentum in the process. This effect has not been reported for emission from an adatom. We believe that that circumstance is a result of the fact that oxygen on tungsten resides below the place defined by the outermost layer of tungsten atoms. While there is no doubt that in a material the internal radiation field is different than the external field, observations attributed to the difference are essentially absent in photoemission studies. The other case where this has been reported and studied is emission from aluminum.

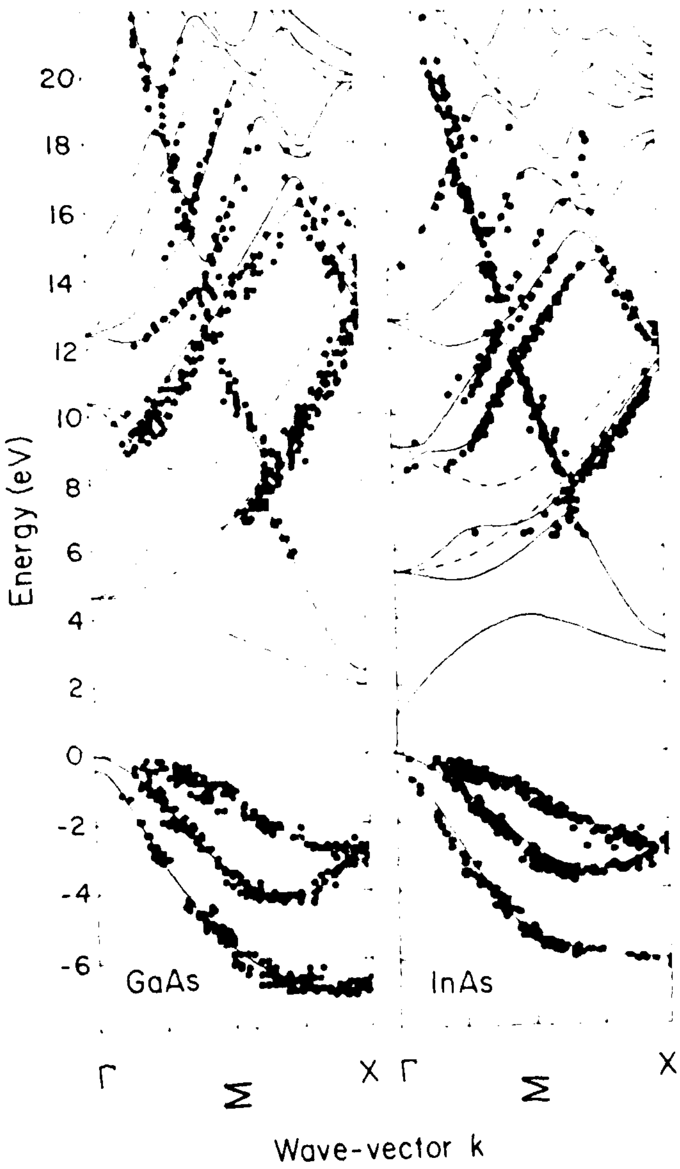

Fig. 1. The comparison of photoemission spectral peaks to the theoretical band by K. Pandey. Each peak gives a conduction and valance band pair of points at a specific value of the wave vector. The spectra were angle-resolved and collected in the direction normal to the (110) cleavage plane.

C. PUBLICATIONS

a. Research Articles

1. "Symmetry-Related Polarization Effects in Angle-Resolved Synchrotron Photoemission from W(001) and W(001) + H," J. Anderson, G.J. Lapeyre, and R.J. Smith, Phys. Rev. B17, 2436 (1978).

2. "Constant Final Energy and Constant Initial Energy Spectroscopy," G.J. Lapeyre, R.J. Smith, J.A. Knapp, and J. Anderson, Journal de Physique 39, C4-134 (1978).

3. "Polarization-Dependent Angle-Resolved Photoemission for Band Structure Studies," R.J. Smith, G.J. Lapeyre, J. Anderson, and G.P. Williams, Proceedings of the International Conference on Physics of Transition Metals, Inst. Phys. Conf. Ser. 39, 220 (1978).

4. "Symmetry Determination of Surface States on GaAs(110) Using Polarizatin-Dependent, Angle-Resolved Photoemission," G.P. Williams, R.J. Smith, and G.J. Lapeyre, J. Vac. Sci. Tech. 15 (1978).

5. "A Grazing Incidence Monochromator," G.P. Williams, Workshop on X-Ray Instrumentation for Sunchrotron Radiation Research SSRL, No. 78/04 Vi-21, (April 1978).

6. "Surface States on Unrelaxed GaAs(110) in the Bond-Orbital Model," W. Schwalm and J. Hermanson, Solid State Commun. 27, 587 (1978).

7. "The Symmetry and Dispersion of Surface States on GaAs(110) Surfaces Determined Using Polarization-Dependent Angle-Resolved Photoemission," G.P. Williams, G.J. Lapeyre, and R.J. Smith, Proceedings of the 14th International Conference on the Physics of Semiconductors, Edenburg, Scotland, p. 1077 (1979).

8. "4f Core Threshold Effects in Photoemission from Pt," G.P. Williams, G.J. Lapeyre, J. Anderson, R.E. Dietz, and Y. Yafet, J. Vac. Sci. Technol. 16 528 (1979).

9. "Initial and Final State Effects in the Photoionization Spin-Orbit Branching Ratios of Core Levels," G. Margaritando, F. Cerrina, G.P. Williams, and G.J. Lapeyre, J. Vac. Sci. Technol. 16, 507 (1979).

10. "Surface Structure Effects Via Photoexcited Core Electron Diffraction for Na on Ni," G.P. Williams, F. Cerrina, I.T. McGovern, and G.J. Lapeyre, Solid State

Commun. 31, 15 (1979).

11. "Initial State Symmetries from Polarization Effects in Angular-Resolved Photoemission," G.J. Lapeyre, J. Anderson, and R.J. Smith, Surf. Sci. 89, 304 (1979).

12. "Synchrotron Radiation Photoemission Studies of Core Level Excitation Effects," G.J. Williams, G.J. Lapeyre, J. Anderson, R.E. Dietz, and Y. Yafet, Surf. Sci. 89, 606 (1979).

13. "Resonant Enhancement in Photoemission from GaSe," G.P. Williams and G.J. Lapeyre, Phys. Rev. B20(12), 5280 (1979).

14. "Further Studies of Ni(001)C(2x2)CO: Evidence for Back Donation in the Chemisorption Bond," R.J. Smith, J. Anderson, and G.J. Lapeyre. Phys. Rev. B15, 1980.

15. "Angle-Resolving Modification for the Co-Cylindrical Mirror Analyzer," J.A. Knapp, G.J. Lapeyre, N.V. Smith, and M.M. Traum, Rev. Sci. Instrum. 53, 781 (1982).

16. "Constant Final State Spectroscopy: Applications to Band Structure Studies--W(100)," R.J. Smith, J. Anderson, J. Hermanson, and G.J. Lapeyre. Submitted to Phys. Rev.

17. "Electronic Structure Studies of the Nb(110) Surface," R.J. Smith, G.P. Williams, J. Colbert, M. Sagurton, and G.J. Lapeyre, Phys. Rev. B22, 1584 (1980).

18. "Resonance Behavior in the Photoemission from W(111) + O_2 System," R. Avci, G.J. Lapeyre, R. Rosei, and J. Anderson, VI Int. Conf. on Vacuum Ultraviolet Radiation Physics, Charlottesville, VA, Extended Abstracts, I-13 (1980).

19. "Enhancement of Photoemission Intensity Near the As-3d Core Level Threshold for Clean GaAs(110) and GaAs(110) + Ge," P. Zurcher, G.J. Lapeyre, and R. Avci, VI Int. Conf. on Vacuum Ultraviolet Radiation Physics, Charlottesville, VA, Extended Abstracts, I-63 (1980).

20. "Unique Advantages of Constant Final Energy Photoemission Spectroscopy (CFS) for Electronic Structure Studies, Nb(110) and W(100)," R.J. Smith, G.P. Williams, and G.J. Lapeyre, VI Int. Conf. on Vacuum Ultraviolet Radiation Physics, Charlottesville, VA, Extended Abstracts, I-30 (1980).

21. "W(111) Surface: An Experimental and Theoretical

Photoemission Study," F.Cerrina, G.P. Williams, J. Anderson, G.J. Lapeyre, O. Bisi, and C. Calandra, Proceedings of the Third European Conference on Surface Science (ECOSS 3) and the 4th International Conference on Solid Surfaces, Suppl. to Le Vide et Les Couches Minces 201, 1162 (1980).

22. "Resonant Surface Photoeffect for an Adsorbte: Oxygen on W(100) and W(111)," R. Avci and G.J. Lapeyre, Submitted.

23. "Core Threshold Photoemission Spectroscopy from the As3d Core Level of GaAs(110) and Effects of Ge Chemisorption," P. Zurcher, G.J. Lapeyre, R. Avci, and J. Anderson, J. Vac. Sci. Technol. 18, 778 (1981).

24. "A Sum-Rule Test for Coherent and Incoherent Contributions to the Photoelectron Cross-Section near Core-Electron Resonances in Metallic Ni and Pt," R.E. Dietz, Y. Yafet, G.P. Williams, G.J. Lapeyre, and J. Anderson, Phys. Rev. B24, 6820 (1981).

25. "An Experimental and Theoretical Study of the Electronic Structure of the W(111) Surface," F. Cerrina, G.P. Williams, J. Anderson, G.J. Lapeyre, and O. Bisi, Recent Developments in Condensed Matter Physics, Vol. 2, J.T. Devreese et al., editors; [Plenum Press, New York, 1981], p. 391.

26. "Observation of Ge-Induced Electronic States at the Ge:GaAs(110) Interface by Means of Polarization-Dependent UPS," P. Zurcher, G.J. Lapeyre, J. Anderson, and D Frankel, J. Vac. Sci. Technol, 21(2), 476 (1982).

27. "W(111): Angle-Resolved Photoemission from the Clean and H_2-covered Surface," F. Cerrina, J.R. Anderson, G.J. Lapeyre, O. Bisi, and C. Calandra, Phys. Rev. B25, (1982).

28. "Study of III-V Semiconductor Band Structures by Synchrotron Photoemission," F. Cerrina, J. Hermanson, J. Anderson, J.A. Knapp, R.J. Smith, and G.J. Lapeyre, 16th International Conference on the Physics of Semiconductors, Montpellier, France, 1982. To be submitted.

29. "Observation of Non-Uniform Energy Band Shifts for Ge on GaAs(110)," P. Zurcher, G.J. Lapeyre, J. Anderson, and D. Frankel, 16th International Conference on the Physics of Semiconductors, Montpellier, France, 1982. In preparation.

b. Conference Talks

i. **Invited Conference Papers**

1. "Constant Final Energy and Constant Initial Energy Spectroscopy," Fifth International Conference on Vacuum Ultraviolet Radiation Physics, Montpellier, France, September, 1977.

2. "Polarization-Dependent Angle-Resolved Photoemisison for Band Structure Studies," International Conference on the Physics of Transition Metals, Toronto, August 1977.

3. "A Grazing Incidence Monochromator," G.P.Williams. Workshop on X-Ray Instrumentation for Synchrotron Radiation Research, SSRL No. 78104, April 1978.

4. "Polarization-Dependent Angle-Resolved Photoemission Spectroscopy of GaSe, GaAs, and W Surfaces," Gordon Conference on Electron Spectroscopy, Waterboro, New Hampshire, July 1978.

5. "Determination of Initial State Symmetry from Polarization Dependence of Photoemission," Second European Conference on Surface Science (ECOSS II), Cambridge, England, March 1979.

6. "The Application of Polarization-Dependent Angle-Resolved Photoemission to Surface Analysis," 34th Northwest Regional American Chemical Society Meeting, Hanford, Washington, June 1979.

7. "Angle-Resolved Ultraviolet Photoemission Spectroscopy," 26th American Vacuum Society Meeting, New York, September 1979.

ii. **Contributed Conference Papers (refereed)**

1. "Core Excitation Studies with Synchrotron Photoemission," G.J. Lapeyre, Inmer Shell Workshop, September 1977, Orsay, France.

2. "Symmetry Determination of Surface States on GaAs(110) Using Polarization-Dependent, Angle-Resolved Photoemission," Conference on Physics of Compound Semiconductor Interfaces, UCLA, January 1978.

3. "The Summetry and Dispersion of Surface States on GaAs(110) Surfaces Determined Using Polarization-Dependent Angle-Resolved Photoemission," 13th Int'l Conference on Physics of Semiconductors, Edinburgh,

September, 1978.

4. "4f Core Threshold Effects in Photoemission from Pt," G.P. Williams, G.J. Lapeyre, J. Anderson, F. Cerrina, and R.E. Dietz, 25th American Vacuum Society Symposium San Francisco, November 1978.

5. "Initial and Final State Effects in the Photoionization Spin-Orbit Branching Ratio of Core Levels," G. Margaritondo, F. Cerrina, and G.J. Lapeyre, 25th American Vacuum Society Symposium, San Francisco, November 1978.

6. "Rapporteur for the Atomic and Electronic Structure Session," 6th Conf. on the Physics of Compound Semiconductor Interfaces, Asilomar, February 1979.

7. "Synchrotron Radiation Photoemission Studies of Core Level Excitation Effects," G.P. Williams, G.J. Lapeyre, J. Anderson, R.E. Dietz, and Y. Yafet, Second European Conf. of Surf. Science, Cambridge, England, April 1979.

8. "Disorder Effects in the Angle-Resolved Photoemission Spectra from GaAs(110)," F. Cerrina and G.J. Lapeyre, International Conference on Solid Surfaces (ICSS), Paris, 1979.

9. "An Experimental and Theoretical Study of the Electronic Structure of the (W(111) Surface, F. Cerrina, G.P. Williams, J. Anderson, G.J. Lapeyre, O. Bisi, and C. Calandra, European Physical Society Conference, Autwerp, 1980.

10. "W(111) Surface: An Experimental and Theoretical Photoemission Study," F. Cerrina, G.P. Williams, J. Anderson, G.J. Lapeyre, O. Bisi, and C. Calandra, 3rd European Conference on Surface Science (ECOSS III) and the International Vacuum Conference VIII, Cannes, France, 1980.

11. "Enhancement of Photoemission Intensity Near the As-3d Core Level Threshold for Clean GaAs(110) and GaAs(110) + Ge," P. Zurcher, R. Rosei, J. Anderson, and G.J. Lapeyre, 6th Int. Conference on Vacuum Ultraviolet Radiation Physics.

12. "Resonance Behavior in the Photoemission from W(111) + O_2 System," R. Avci, R. Rosei, J. Anderson, and G.J. Lapeyre, ibid.

13. "Unique Advantages of Constant Final-Energy Photoemission Spectroscopy (CFS) for Electronic Structure Studies: Nb(110) and W(100)," R.J. Smith, G.P. Williams, and G.J. Lapeyre, ibid.

14. "Photoemission Results on the Conduction Band and Valence Band of GaAs and Resonance Effect for Oxygen on W," G.J. Lapeyre, et al., 27th American Vacuum Society Meeting, Detroit, 1980.

15. "Observation of a Surface Photoelectric Effect for Oxygen on Tungsten," R. Avci and G.J. Lapeyre, 41st Annual Conference on Physical Electronics, Bozeman, MT, June 1981.

16. "Observations of Ge-Induced Electronic States at the Ge-GaAs(110) Interface by Means of Polarization-Dependent UPS," P. Zurcher, J. Anderson, and G.J. Lapeyre, Physics of Compound Semiconductor Interfaces Conference, Asilomar, January 1982.

iii. **Contributed Conference Papers**

1. "Final-State Resonances in Core Level Photoemission Spectra," G.J. Lapeyre and G.P. Williams, March Meeting of the American Physical Society, Washington, D.C., March 1978.

2. "Symmetry of Surface States Observed in Polarization-Dependent Angle-Resolved Photoemission Spectroscopy of W(111)," J. Hermanson, M. Kawajiri, J.R. Anderson, and G.J. Lapeyre, ibid.

3. "Surface States on Unrelaxed GaAs(110) in the Bond-Orbital Model," W. Schwalm and J. Hermanson, ibid.

4. "3p Core Threshold Effects in Valence Photoemission from Ni," G.P. Williams, G.J. Lapeyre, F. Cerrina, J. Anderson, R.E. Dietz, and Y. Yafet, American Phys. Soc. Meeting, Chicago, March 1979.

5. "4f Core Threshold Effects in Valence Photoemission from Pt," R.E. Dietz and Y. Yafet, G.P. Williams, G.J. Lapeyre, and J. Anderson, American Phys. Soc. Meeting, Chicago, March 1979.

6. "Photoemission Results on the Conduction Band and Valence Band of GaAs and Resonance Effect of Oxygen on W," G.J. Lapeyre, Synchrotron Radiation Center Users' Group Meeting, Madison, October 1980.

7. "Electronic Structure of Nb(110)," G.P. Williams, R.J. Smith, and G.J. Lapeyre, APS Meeting, New York, March 1980.

8. "Photoemission Studies of GaAs(110) and Oxygen on Tungsten," G.J. Lapeyre, P. Zurcher, R. Avci, D. Frankel, and J. Anderson, Synchrotron Radiation Center Users' Group Meeting, Madison, October 1981.

c. **Seminars**

General Motors Research Laboratory, Warren, Michigan, March, 1977
Institut Fur Festkorperforschung, Julich, Germany, Sept. 20, 1977
Deutshes Elektronen-Synchrotron D.E.S.Y. Hamburg, Germany, Sept. 1978
University of Liverpool, England, September 1978
Technische Hochschole, Garching, Munich, Sept. 1978
Honeywell, Inc., Research Center, Minneapolis, Sept. 1978
University of Nebraska, December, 1979
University of Texas, April, 1980
University of Houston, April, 1980
American Chemical Society, American Society for Metals Society for Applied Spectroscopy, Idaho Falls, April, 1980
University of Notre Dame, July, 1980
Xerox Webster Research Center, Rochester, NY, July, 1980
Bell Laboratories, Murray Hill, September, 1981
University of Pennsylvania, Philadelphia, September, 1981
IBM Research Center, Yorktown Heights, September, 1981

d. Thesis

"Tight-Binding Methods for the Study of Surface States on Semiconductors," W.A. Schwalm, Doctoral Dissertation, June 1978.

D. Professional Personnel - July 1, 1977 to April 30, 1982

Principal Investigator

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Professor of Physics

Theoretical Associate

John C. Hermanson
Professor of Physics

Research Associates (post-doctoral)

James R. Anderson
Gwyn P. Williams
Franco Cerrina
Recep Avci
Peter Zurcher
David J. Frankel
Franz Stucki

Research Assistants (students)

William A. Schwalm, Ph.D. completed 1977
James R. Myron, Ph.D. expected completion 1983
Peter Kosso, M.S. Student
Johannes Raab, M.S. Student
Mark Dickson, M.S. Student

E. Coupling

a. Program to study Fano resonances at 4f core thresholds in Pt with R.E. Dietz and Y. Yafet, Bell Telephone Laboratories.

b. Performed synchrotron radiation UPS experiments for T. Murovio of Honeywell Research Labs, Minneapolis, on carbon films with diamond-like properties, a program also supported by AFOSR.

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